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of:

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for

Stretch Blow-Molded Stackable Tumbler

STRETCH BLOW-MOLDED STACKABLE TUMBLER

Claim for Priority

This application claims the benefit of the filing date of U.S. Provisional Patent Application Serial No. 60/402,314, filed August 9, 2002.

Technical Field

The present invention relates generally to drinking vessels and in preferred embodiments to a stretch blow-molded tumbler formed from an injection molded preform which is expanded radially and axially to form the tumbler. The tumblers exhibit high Rigidity, orientation and relatively high crystallinity.

Background

In quick service restaurants, one of the highest margin items offered is the fountain beverage. In many cases, it is possible for the quick service restaurant owners to boost their sales of beverages by providing promotional cups either with printing tied to some media phenomenon, such as a popular children's movie or by offering cups in an unusual configuration. However, the ability to offer cups in unusual configurations or shapes is greatly limited by the technology currently used to produce such cups. In particular, injection-molding is relatively inefficient in use of materials when cups are formed from polymeric resins, while injection blow-molding is best applied to only a limited range of polymers and vacuum thermoforming produces a relatively weak cup. The cups produced by these methods are usually limited to traditional straight taper designs and are usually not transparent, particularly in large sizes as are typically employed in connection with promotional cups.

We have found that we can produce high strength cups with improved attributes from relatively small amounts of resin using a stretch blow-molding technique followed by a rim fortifying process. In particular, these cups have high Rigidity as the stretch blow-molding process orients the polymer axially as well as radially during the forming process and thereby increases the Rigidity of the cup considerably as compared to cups prepared by technologies that do not orient the polymers in both directions. A stretch blow-molding process makes it possible to use much higher molecular weight polymers and can induce increased crystallinity. Therefore the cups produced are stronger for this reason as well. Unique product benefits include: unmatched strength, clarity, printability, and the versatility to make reverse taper shapes or blow-molded embossed sidewall designs or logos. As will be appreciated from the comparisons described hereinafter, the cups or tumblers of the invention exhibit improved properties, especially Rigidity as compared with conventional cups. For example, there is reported in United States Patent No. 6,554,154 to *Chauhan et al.* Rigidity data for thermoformed cups which are five times (5X) lower at 1 inch deflection than Relative Cup Rigidity values realized with the invention at 1 inch deflection.

The following patents are generally illustrative extrusion and injection blow-molding art, the disclosures of which are incorporated herein by reference.

Blow-molded containers are well known in the form of bottles, cans, jars and the like. There is disclosed in United States Patent No. 6,237,791 to *Beck et al.* a method of making wide mouth containers by way of stretch blow-molding, which containers include threads or flanges so they may be used as jars or "hot-fill" food containers. The containers are prepared by stretch blow-molding a bottle, heat-setting the bottle and removing the upper neck portion. In some embodiments a curled rim is provided about the upper opening of the container by way of heating the upper sidewall of the bottle to or above its glass transition temperature, Tg, and curling the

sidewall to form a curled rim. The containers may have a base with an annular peripheral chime surrounding an inward sloping base portion if so desired. *See* United States Patent Nos. 4,889,752 to *Beck.*

United States Patent No. 4,665,682 to *Kerins et al.* discloses a method of making polyester containers including blow-molding a bottle and severing the upper portion to make a jar or can.

United States Patent No. 4,559,197 to *Dick et al.* discloses a method and apparatus for flanging a tubular polyester article in order to make a polyester can. The flange is used for sealing the can with a curled end unit as is well known in the art.

Stretch blow-molding is perhaps one of the most widely employed methods for making blow-molded bottles; however, the method is not believed to have been employed to make stackable drinking vessels. Rather, plastic blow-molded cups have been produced by the method of United States Patent No. 4,540,543 to Canada Cup, Inc. where a stretch-rod is not used and the preform has a large opening. This process is more intricate to coordinate than stretch blow-molding processes and does not utilize generally available molding equipment since the injection-molding and blow-molding operations are practiced concurrently. Moreover, the process of the '543 patent does not extend the length of the injection molded parison and thus generally requires a relatively thin-walled parison which, in turn, restricts the selection of polymer material utilized in the process. So also, the process of the '543 patent does not include heating the parison sufficiently to relieve molded-in stress.

<u>Summary of Invention</u>

The tumblers of the invention are typically relatively rigid including a base, a sidewall and an upper aperture preferably prepared by stretch blow-molding an

injection-molded preform at blow-up ratios of 3 or more. The tumblers exhibit a Rigidity Index of more than 1.25 lb_f fluid oz./gram at 2/3 cup height and ¼ inch sidewall deflection. Rigidity Indices of about 1.35, 1.4 and higher are still more preferred; Rigidity Indices from about 1.4 to about 2 are typical. The Relative Cup Rigidity is equal to the Rigidity Index for PET tumblers made of the reference resin; but may differ somewhat for resins of different composition. As used herein, PET *per se* refers to polymer resins consisting essentially of ethylene terephthalate repeat units, that is, over about 90 mole %; while other PET polymers may have more comonomer(s) as hereinafter discussed.

The tumblers typically exhibit a Rigidity of at least 4 or 5 lb_f at 2/3 cup height and 1 inch sidewall deflection as is seen in Table 6 hereinafter. A weight to volume ratio of less than about 1.2 gram/oz. is preferred; the volume being the contained volume of the tumbler. Weight to volume ratios of about 1g/oz. or less are still more preferred. The inventive process provides relatively high crystallinity in the sidewall as will be seen from the calorimetry data which follows. Crystallinities of 20%, 25% and higher may readily be achieved with PET. The high Rigidity makes the process especially suitable for large tumblers of low weight. Tumblers of 20 fluid oz. volumes, 30 fluid oz. volumes and more are advantageously fabricated in accordance with the invention.

The Rigidity Index (hereinafter defined) of the cups of the invention tend to be significantly higher than those of other disposable cups. This is perhaps better appreciated by reference to **Figure 1**, where it is seen the cups of the invention exhibit Rigidity Index Values of 1.4 and higher while values of 1.2 and lower were observed for other products.

One preferred method of making a blow-molded tumbler includes: (a) injection-molding a preform provided with a neck portion, a body portion and a

bottom portion; (b) blow-molding the preform to form a first intermediate article therefrom wherein the preform is expanded radially as well as axially, the intermediate article being characterized by having a neck portion corresponding to the neck portion of the preform, a transition portion adjacent the neck portion of the first intermediate article and a tumbler portion adjacent the transition portion thereof, the tumbler portion of the first intermediate article being further characterized by having a base formed from the bottom portion of the preform and a sidewall formed from the body portion of the preform; (c) severing the tumbler portion of the first intermediate article from its transition portion to form a second intermediate article having a base corresponding to the base of the first intermediate article and a sidewall extending upwardly therefrom to define an upper aperture, the aperture being generally larger in area than the base of the second intermediate article such that the tumbler portions are stackable; and (d) fortifying the sidewall of the second intermediate article around the upper aperture to form the tumbler. Typically the step of blow-molding the preform includes, reheating the preform after it is injection molded, stretching the preform with a solid or hollow stretch rod prior to blow-molding, and then blow-molding the bottle, usually first with a low pressure and then with high pressure. Alternatively, uniform pressure may be used, but this is not preferred for the present invention. Generally, the first intermediate article has an axial stretch ratio of 1.5 to 7 and a hoop stretch ratio of 1.5 to 10. In some cases, the first intermediate article has an axial stretch ratio of 2.0 to 3.5 times and a hoop stretch ratio of 1.5 to 4. A blow-up ratio (hereinafter defined) of at least 3 is desirable, typically a blow-up ratio of at least 5 is used. Blow-up ratios of from about 7.5 to about 14 with respect to the preform are preferred in some cases; for instance, the first intermediate article may have a blow-up ratio of from about 9 to about 12. The tumblers or cups of the invention are stackable because their bases have a perimeter that is smaller than the inner perimeter of their upper apertures and of suitable shape, such that one tumbler may be stacked with a like tumbler. Preferably, the tumbler's perimeter from its base up to about 60% of its height is likewise smaller than the interior of its upper aperture so that the

lower 60% at least fits within a lower adjacent tumbler in a stack. In many cases, it is desirable that the tumbler's perimeter at its base and its perimeter up to at least 90 or 95% of its height is smaller than the interior of its upper aperture such that the tumblers are compactly stackable.

While any suitable resin composition may be used, resins without mineral filler are preferred in many embodiments.

Typically, the tumbler has a generally circular cross-section and comprises in some embodiments a polyethylene terephthalate ("PET") polymer. The tumbler may consist essentially of polyethylene terephthalate having an intrinsic viscosity of from about 0.55 to about 1.05. An intrinsic viscosity of about 0.72 or greater is sometimes desirable. Typically, the preform has a weight of from about 10 grams to about 200 grams, whereas the tumbler has a contained volume of at least about 7 fluid oz. Sometimes the preforms weigh between about 25 grams and 100 grams. A tumbler volume of from about 12 oz. to 64 oz. is typical as is an outward taper from its base to its upper aperture of from about 2°to about 12°. A tumbler volume of from about 20 to about 35 fluid oz. is typical in many embodiments, especially for promotional cups. In some cases a taper from the tumbler base to its upper aperture of from about 3°to about 8°is preferred and the tumbler has a reverse (or inward) taper over a portion of its sidewall. Preferably, the tumbler has a generally smooth sidewall adjacent its fortified rim, free from thread features. Generally, the tumbler rim has a lateral thickness of from about 1.5 to about 10 times the thickness of the sidewall adjacent its fortified rim. The tumbler sidewall usually has a wall caliper of generally from about 0.005 inches to about 0.100 inches, covering the range of lightweight, disposable tumblers to heavy weight, reusable products. Reusable products may have a wall caliper of from about 0.025 inches to about 0.09 inches; typically in the range of from about 0.040 to about 0.080 inches; significantly thicker than blow-molded bottles, for example.

The tumblers may be made in a variety of shapes including oval cross-sections, rounded square cross-sections, rounded triangular cross-sections and so forth. A tumbler may have a cross-sectional shape selected from the group consisting of non-circular ovals, rounded polygons and combinations of curved and linear segments forming a closed perimeter. Likewise, there may be included features such as grips, handle portions or other surface features. For example, one could include tooling with insertable logos in the blow-molds for producing products for different promotional campaigns.

In a particularly preferred embodiment, the first intermediate article is provided with a circumferential cutting notch or knife guide joining the transition portion with the tumbler portion, as well as provided with a circumferential groove in the transition portion of the first intermediate article adapted to receive a drive member for rotating the article during the step of severing the tumbler portion therefrom.

The step of fortifying the sidewall of the second intermediate article around the upper aperture may involve shaping the dome portion of the bottle such that the angle of the severed end remaining on the intermediate article will facilitate the formation of a fortified rim. The action required to form the fortified rim may range from pinching two sidewalls together to reshaping the severed end such that the end of the fortifying portion follows a curvilinear path, which may be varied up to 360°or more. In a typical case, the tumbler is made from a polyethylene terephthalate polymer and the fortified lip is provided with a die or other curling tool, such as a curling screw, maintained at a temperature of from about 275°F to about 350°F. A die maintained at a temperature of from about 285°F to about 330°F is suitable for PET, which may also be cold curled. The curling tool may be a worm gear-type screw, a paper cup brim forming die, a can double seamer, or a curling die which may

be operated from about typical room ambient temperatures to about 325°F for PET. In typical cases, the curling tool is operated from ambient temperatures up to the glass transition temperature of the polymer.

The step of fortifying the sidewall of the second intermediate article around the upper aperture may alternatively include applying a rim-forming member to the sidewall around the upper aperture, preferably wherein the rim-forming member is the same material as the tumbler. The rim-forming member may be an end unit including a lid portion, wherein at least a part of the lid portion is removable and includes a removable pull-tab. The rim-forming member may have a U-shaped profile. Likewise, the sidewall of the tumbler around the upper aperture may be configured to have a downwardly projecting U-shaped terminal portion interlocked with an upwardly projecting U-shaped terminal portion of the rim-forming member.

The tumbler portion of the first intermediate article may be provided with a flange projecting inwardly or outwardly from its sidewall joining the tumbler portion of the first intermediate article to the transition portion thereof. The flange may project downwardly as well and is generally configured to be incorporated into the fortified rim of the tumbler and facilitate formation of the tumbler rim.

The preform from which the tumbler is made need not be threaded. Inasmuch as the neck portion of the first intermediate article is severed in any event, it is only necessary to have some means for securing the preform during blow-molding; in this respect, either a flange projecting outwardly from the preform at its upper portion or a recess formed therein is sufficient.

In another aspect of the invention, there is provided a stackable tumbler produced by blow-molding a preform wherein the preform is expanded radially and axially to form the tumbler which is characterized by a sidewall, an upper aperture

and a base wherein the upper aperture is of generally larger area than the base and the sidewall is provided with a fortified rim around the upper aperture. Here again, the tumbler generally has an axial stretch ratio of 1.5 to 7 times and a hoop stretch ratio of 1.5 to 10 times. Usually the tumbler has an axial stretch ratio of 2.0 to 3.5 times and a hoop stretch ratio of 1.5 to 4 times with respect to the preform. The tumbler may have a weight of from about 10 to about 200 grams and typically has a contained volume of at least 7 fluid oz. as noted above; sometimes a contained volume of at least about 12 oz. up to typically 64 oz., but sometimes as high as 96 oz., which is beyond the normal consumption needs of an individual but which may be fitted with a handle or carrying device and a lid with a pour spout.

Optionally, the method of the invention includes a heat-setting step in connection with the blow-molding of the first intermediate article. The first intermediate article is heat-set in the blow-mold by controlling the temperature of the blow-mold and the "residence time" of the first intermediate article in the mold. This procedure is particularly advantageous for reusable cups which are relatively thick-walled. The residence time is (for practical purposes) the time in seconds from commencing either stretching or blowing of the preform to the mold being opened for removal of the blow-molded container. The residence time and mold temperature may be controlled to achieve the desired crystallinity, which may be from about 25 to about 45% (on a weight basis) and in some embodiments from about 35% to about 42%. A preferred method of determining crystallinity is to use differential scanning calorimetry. Alternatively, ASTM Method 1505 provides a density gradient method. The temperature of the blow-mold on its portion corresponding to the sidewall of the tumbler is generally maintained at a temperature of from about 200°F to about to about 350° with from about 250°F to about 280°F being typical for heat setting. The temperature of the blow-mold at its portion corresponding to the base of the tumbler is generally maintained at a temperature of at least about 150°F during heat-setting and typically at a temperature of at least about 165°F, which is less than the

temperature of the mold at its portion corresponding to the sidewall of the tumbler. Residence times for heat-setting cycles may be from 0.5 to 5 seconds with from about 1 to about 3 seconds being typical.

The tumblers may be made from a multilayer or laminated preform which contains, for example, a barrier layer of ethylene vinylalcohol, polyamide such as nylon or vinylidene chloride polymer. Other functional layers might include a thermally conductive layer, for example, a layer containing heat conducting materials such as carbon black, carbon nanotubes (buckytubes), metallic fibers or particles, or inherently conductive polymers. In some cases, if delamination is sought, adjacent layers may be formed from polymers which form a low adhesion interface such as PET and polypropylene or reactive agents may be used to generate a gas to foam the layers and/or separate them. Suitable reactive agents may be foaming agents such as sodium bicarbonate on one layer and citric acid on an adjacent layer. Heat-setting the article in the mold can be especially advantageous in connection with multilayer preforms wherein one layer has not been heated above its orientation temperature during the blow-molding process. For example, at PET/PP multilayer preform could be blow-molded at 200°F or so which may be sufficient to orient the PET which typically has an orientation temperature of from about 190°F to 240°F, but not sufficient to orient the polypropylene, which has an orientation temperature of from about 250°F to about 280°F. If the article is heat set at 275°F or so, the orientation temperature of the polypropylene may be exceeded and the polymer will orient in the desired configuration.

The multilayer preform may contain two contiguous layers of polymer with different compositions, but including a common monomeric repeat unit to improve compatibility and adhesion of the various layers while providing for a spectrum of properties. For example, there could be provided an interior layer of polypropylene

copolymer which is relatively stiff and an outer layer of polypropylene copolymer which is relatively soft to improve "hand feel" of the tumblers.

The tumblers of the invention may be made of any suitable material in addition to PET. Suitable materials may include: polystyrene; polycarbonate; styrene; acrylonitrile; polyvinyl chloride; polyolefin polymers including polypropylene, cyclic polyolefin copolymers, polyethylene, polybutylene polymers and the like; polyamide polymers; polysulfones; polyacetals; polyarylates; polyacrylonitrile –stryrene copolymers; polyolefin ionomers; styrene-acrylonitrile copolymers; environmentally degradable polymers and mixtures thereof, as is described hereinafter. The inventive method provides remarkable improvements in many cases. For example, a styrene tumbler made by the inventive method resists splitting upon flexing to a remarkable degree as compared with polystyrene cups made by other methods.

In some embodiments, the tumblers of the invention can be made relatively thick-walled, e.g., a wall thickness of greater than 25 thousandths of an inch such that it is not necessary to fortify the rim; rather the tumbler portion may simply be severed from the upper portion of the intermediate article and the rim optionally smoothed with a flame treatment, abrasive, or other honing technique. Of course, curling the rim or flanging it with a hot tool will likewise provide the needed smoothness after cutting the tumbler from the transition section.

Still yet another technique for making the inventive cups is by molding them directly in a stretch blow-molding process of the type described in United States Patent No. 4,731,011 to *Nakamura et al.*, the disclosure of which is incorporated herein by reference. In this process the rim of the preform is not expanded and corresponds to the rim of the tumbler so that severing a portion of an intermediate article is not required. Generally, the rim of the tumbler is from about 1.2 to 5 times

the thickness of the adjacent sidewall of the tumbler when employing this process as noted hereinafter.

These and other features and advantages of the present invention will be better understood by considering the following description and appended drawings.

Brief Description of Drawings

The invention is described in detail below with reference to the drawings wherein like numerals designate similar parts and wherein:

Figure 1 is a comparison of observed Rigidity Index values, comprising disposable cups of the invention with various other cups.

Figure 2A is a schematic view in elevation of a preform used for making a tumbler of the invention;

Figure 2B is a schematic view in elevation of an alternate design of a preform used for making a tumbler of the invention;

Figure 3 is a schematic view in elevation of a blow-mold with a stretch rod and an intermediate article of the invention;

Figure 4A is a schematic view in elevation of a first intermediate article of the invention;

Figure 4B is a partial schematic view in elevation of another configuration of a first intermediate article of the invention;

Figure 4C is yet another partial schematic view in elevation of still another configuration of a first intermediate article of the invention;

Figure 5 is a schematic view in elevation of a second intermediate article of the invention wherein the transition portion has been severed;

Figures 6-10 are schematic diagrams illustrating providing a lip curl to the second intermediate article of **Figure 4**;

Figure 11 is a perspective view of a tumbler of the invention;

Figures 12 and **13** are schematic diagrams illustrating a fortified rim of a tumbler of the present invention provided by way of using a U-shaped rim forming member;

Figures 14-17 are schematic diagrams illustrating a lidded tumbler of the invention wherein the lid is formed with a double sealing end unit; and

Figure 18 is a schematic view in elevation of another blow-mold for fabricating biaxially-oriented tumblers of the invention.

<u>Detailed Description</u>

The invention is described in detail below with reference to numerous embodiments, which description is provided for purposes of illustration only. Modifications to those embodiments, within the spirit and scope of the present invention, set forth in the appended claims, will be readily apparent.

Unless otherwise defined or the context clearly indicates a more specific meaning, terminology as used herein is given its ordinary meaning. "Tumbler", for

example, refers to a stemless drinking vessel. "Taper" refers to the angle with a vertical defined by a line from the base of a tumbler to its rim. A "polyethylene terephthalate" or "PET" polymer is a polymer having more than 50 mole % polyethylene terephthalate repeat units, whereas a polymer or material "consisting essentially of" polyethylene terephthalate has at least about 90% on a molar basis polyethylene terephthalate repeat units. Such materials are sometimes referred to in the art as "bottle resin" and may include, for example, isophthalic residues if so desired. "Caliper" refers to the thickness of an article or the thickness at a particular point in the article as the context indicates.

"Axial" and "hoop stretch" ratios as used herein are characteristics of a blow-molded article with respect to its preform and express the amount of expansion a preform undergoes to make the blow-molded article. "The Blow-Up Ratio" (BUR) is a combined ratio in which the axial stretch ratio is multiplied by the hoop stretch ratio to give an overall or blow-up ratio. The equations for calculating the axial, hoop, and blow-up ratios are as follows:

$$\text{Axial Stretch Ratio} = \frac{La}{Lp}$$

$$\text{Hoop Stretch Ratio} = \frac{Da}{Dp}$$

$$\text{Blow-Up Ratio (BUR)} = (\text{Axial Stretch Ratio}) \times (\text{Hoop Stretch Ratio})$$

wherein:

Da = the maximum inside diameter of the article at the midpoint height

Dp = the minimum inside diameter of the preform at the midpoint height

La = the length of the article below the neck (typically measured from the capping ring minus 0.100 inch to the top of the push-up on the inside of the article)

Lp = the length of the preform below the neck (typically measured from the capping ring minus 0.100 inch to the bottom of the inside surface of the preform)

For articles or preforms with a non-circular cross-section, the diameters employed for purposes of calculating the draw ratio may be based on the corresponding cross-sectional area, for instance, the diameter may be taken as the square root of $4/\pi$ times the corresponding area.

When a polymeric material has a higher molecular weight or the polymer is oriented, many of the attributes desired in the products are enhanced; because increased molecular weight, increased orientation, and increased crystallinity work predominantly toward enhancing the desirable physical properties of the products, it is desirable to devise fabrication procedures which allow for realizing the potential of the material. Table 1 below lists the physical properties and other attributes of polymeric articles and whether that property increases or decreases with increasing molecular weight, increased orientation, or increasing crystallization.

Table 1 – Property Relationships With Molecular Weight, Orientation and Crystallization

Property	Increasing Molecular Weight	Increased Orientation	Increasing Crystallization
Tensile Strength	+	+	+
Modulus	+	+	+
Yield Strength	+	+	+
Elongation	+	-	-
Impact (Toughness)	+	+	+ / -
Hardness	+	+	+
Abrasion Resistance	+	+	+
Chemical Resistance	+	+	+
Environmental Stress Cracking Resistance	+	+	+ / -
Barrier Properties	+	+	+
Adhesion	-	-	-
Solubility	-	-	-

+ Property increases
- Property decreases

Another benefit of the stretch blow-molding process is the annealing that takes place to relieve the stress in the injection-molded preform. The result is primarily a stress-free product that is highly biaxially orientated. This property is of particular interest in heavier weight tumblers that will be washed and reused in a casual dining setting where environmental stress cracking results from dishwasher detergents. Plastic cups that have problems with detergent stress cracking have limited life cycles and, thus, provide a lower value to the purchaser. The two most critical parameters that will reduce or eliminate environmental stress cracking (ESCR) are increased molecular weight (decrease in melt flow) and stress free products. Polycarbonate (PC), for example, has an ESCR problem with strongly alkaline detergents. Heavy weight polycarbonate tumblers (used in casual dining restaurants) made by the injection blow-molding process using 22 melt flow PC begin to stress crack (1/4 inch cracks) after 6 dish washer cycles. When the molecular weight is increased to 10 melt flow PC, the equivalent level of stress cracking does not appear until after the 34th wash cycle. However, the limit on the ability to increase molecular weight is defined by the wall thickness of the product and the height of the tumbler. The flow properties of the polymer need to allow timely filling

of a multi-cavity injection mold. As the size of the cup increases in volume or height, increasing the molecular weight is difficult with prior art processes such as that of the '543 patent noted above ("IBM" process) because the preform is the length of the cup and when it is blown it is only stretched in the hoop direction. The preform stresses are not annealed out in the IBM process and can only be controlled by rigorous temperature control in the mold. Once made, the solidified, but still hot, preform is shuttled to a blow cavity and blow-molded. ESCR related problems in polycarbonate made by the IBM process are as follows: blow-up ratios for the IBM process are low and uniaxial; stress-free parts are not produced; and the polycarbonate is not "blown" in the ideal temperature range for orientation.

Heavy weight polycarbonate cups made by the two-step stretch blow-molding process eliminate these disadvantages. The stretch blow-molding process uses a higher molecular weight polycarbonate resin; the reheating process anneals the stress out of the preform; and the preform temperature can be precisely controlled so that blow-molding takes place in the ideal temperature range for orientation. When these conditions are met the tumbler or cup will have greatly reduced molded-in stress and greatly improved ESCR performance.

The various features of the invention will be better understood by reference to the drawings.

There is shown in **Figures 2A** and **2B** alternative designs of an injection molded preform **10** having generally a preform length **12** below its neck **14**. Neck **14** is provided with a flange **16** as well as optional threads indicated at **18** in **Figure 2A**. The threads and/or flange **16** may be used to hold the preform in place during processing. A preform designed specifically for blow-molding a tumbler as shown in **Figure 2B** has a cost advantage in that no threads are needed in the neck area and only a small flange is needed to hold the preform in the mold. Cost savings would

result from (1) reducing the weight of the preform and (2) lowering the mold costs by eliminating thread splits. Typically, soda bottle preforms weigh about 26 grams for a 20-oz. bottle and 48.5 grams for a 2-liter bottle. Tumblers of this invention may vary considerably in weight depending on the intended final use. If the intended use were to provide a foodservice customer with a take-out tumbler for soda, then a lightweight tumbler would be appropriate. If the customer is a dine-in customer who uses a tumbler that the casual dining restaurant washes and reuses multiple times, then the tumbler needs to be made using a heavy weight construction for durability. Therefore, the weight range from lightweight use to a heavy weight use can be considerable. For example, a 22-oz. tumbler for take-out could weigh as little as 16-18 grams and a reusable tumbler of the same size could weigh 50 to 95 grams. Preform **10** may be relatively thick, having a wall thickness **20** of generally from 0.060 inches to 0.180 inches, which need not be a constant thickness over its body portion **22** and bottom portion **24**; the thickness can be optimized to provide enhanced Rigidity about 2/3 of the way up from the base by thickening at this level.

Figure 2B depicts a multilayer preform **10** provided with an outer layer **17**, an inner layer **19** and an intermediate layer **21** which may be a barrier layer if so desired. So also, contiguous layers may be provided with reactive chemicals and so forth as noted above, or may be materials such as polypropylene and PET which do not readily adhere to one another. If so desired, one or more of the layers may be further provided with functional attributes such as high or low thermal conductivity if so desired. So also, adhesives may be employed when delamination is to be avoided.

Preferably, the preform comprises a PET polymer and in preferred embodiments is made of bottle resin having an intrinsic viscosity or IV (a measure of molecular weight) of from about 0.55 to about 1.05 as measured according to ASTM D4603, Standardized Test Method for Determining Inherent Viscosity of PET. This test standard also establishes a method for calculating Intrinsic Viscosity. The

primary equipment used is a capillary viscometer, such as the Cannon Ubbelohde Type 1B Viscometer referred to in ASTM D4603.

The IV or intrinsic viscosity of a PET sample is a relative number and represents a measure of its average molecular weight. An IV is determined by dissolving between ¼% and ½% PET in a solvent and measuring the time required for 100 ml of the solution to flow through a capillary. Concentration and time are then used to mathematically compute the IV. The term "inherent viscosity" refers to any IV determined at a specific concentration of the PET solution. A series of IV's are determined at varying concentrations and the data plotted on a curve of IV vs. concentration. The curve is extrapolated back to zero concentration, and this point is defined as the "intrinsic viscosity."

Preform **10** is typically preheated to a temperature of from about 190°F to 240°F or so when made from PET so that it may be blow-molded as shown schematically in **Figure 3**.

The blow-up ratio (BUR) for PET tumblers of this invention generally range from about 3 to about 14.

Figure 3 illustrates schematically a blow-mold **30** having mold halves **32** and **34** as well as a stretch rod **36** used to stretch preform **10** in a stretch blow-molding step. Preform **10** is positioned in mold **30** and stretched with rod **36** and a blow-head provides pressurized air into the interior of the preform. The preform is thus expanded axially as well as radially in mold **30** to form a first intermediate article **40** (**Figures 3, 4A, 4B, 4C**) having a length **42** and a maximum outside diameter **44**.

When using a preform having a length **12** of four inches or so, intermediate article **40** may have a length **42** of 8 inches or so. Diameter **44** may be about 3.5

inches when using a preform having an inside diameter **46** of an inch or so. The axial and hoop stretch ratios with respect to preform **10** are thus:

$$\text{Axial Stretch Ratio} = \frac{8}{4} = 2$$

$$\text{Hoop Stretch Ratio} = \frac{3.5}{1} = 3.5$$

Thus, the Blow-Up Ratio (BUR) is (Axial Stretch Ratio) x (Hoop Stretch Ratio) or (2 x 3.5) = 7

Stackable tumblers of the invention may be blow-molded from clear materials such as: PS (polystyrene), PC (polycarbonate), SAN (styrene acrylonitrile), PVC (polyvinyl chloride), PP (polypropylene), nylon, COC (cyclic polyolefin copolymers), and other polyolefins, and may be combined in multi-layer constructions with barrier materials such as ethylene vinyl alcohol (EVOH), Nylon MXD6 from Mitsubishi Gas Chemical Company, Inc., or with oxygen scavenging materials and with adhesive layers as appropriate. Other suitable polymers may include polysulfones, polyacetals, polarylates (wholly aromatic polyesters), ionomeric polyolefins sold under the tradename Surlyn® and environmentally degradable polymers. Environmentally degradable plastics generally include those which undergo significant changes in their chemical structure under specific environmental conditions, such polymers include oxidatively degradable polymers, photodegradable polymers, and biodegradable polymers. A biodegradable plastic polymer is a material in which the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi and algae. Suitable polymers are described in Volume 19 of the Kirk-Othmer Encyclopedia of Chemical Technology, 4th Ed., pp. 983-996 (Wiley) the disclosure of which is incorporated herein by reference. Carboxylated polymers are generally a preferred class, including poly(lactic acid), polyanhydrides, functionalized natural polymers and so forth. Insofar as the tumblers of the invention are concerned, the

polymer selected must have sufficient moisture resistance for the products' intended end uses. Preferred biodegradable polymers including polylactic acid, polyhydroxybutyrate and polycaprolactones which may optionally be melt-blended with PET.

Suitable polymer compositions include melt blends of cycloolefin copolymers of norbornene and ethylene with various polyethylene polymers. Cycloolefin copolymers are described in United States Patent No. 5,698,645 to *Weller et al.*, the disclosure of which is incorporated herein by reference. The various polyethylene polymers referred to herein are described at length in the Encyclopedia of Polymer Science & Engineering (2 Ed), Vol. 6, pp. 383-522, Wiley 1986, the disclosure of which is also incorporated herein by reference. HDPE refers to high density polyethylene which is generally linear and has a density of generally greater than 0.94 up to about 0.97 g/cc. LDPE refers to low density polyethylene which is characterized by relatively long chain branching and a density of about 0.912 to about 0.925 g/cc. LLDPE or linear low density polyethylene is characterized by short chain branching and a density of from about 0.92 to about 0.94 g/cc. Finally, intermediate density polyethylene (MDPE) is characterized by relatively low branching and a density of from about 0.925 to about 0.94 g/cc. Unless otherwise indicated, these terms have the above meaning throughout the description and claims.

The materials may be tinted; colored with opaque organic or inorganic pigments; contain fillers such as calcium carbonate, talc, mica, nano-size particulates, flame retardants, nucleating agents, clarifiers, antistats, foaming agents; and/or combined with blends of any of the listed polymers with or without compatibilizing agents or in combination with biodegradable polymers.

Monolayer performs may contain multiple colors of dispersed regions of colorants so that the stretch blow-molded article has the visual effect of swirl or

marbleized patterns of distinguishable colors. Multilayer performs may contain different colors in layers of different thickness so that, when blow-molded, the colors of the thicker layers predominate as the background color and the thinner layer produces color differentiated patterns. Dispersed flakes or particles that add a sparkle effect to the blow-molded article may be added in combination with colorants in monolayer or multilayer constructions.

Nano-size particulates may be clays, conductive carbons, silicas, titanium dioxide, aluminum trihydrate, or similar sized materials chosen to enhance a specific property such as modulus, tensile strength, fire retardancy, insulation, conductivity, visual appearance, or tactile feel. The process of the present invention is particularly useful in connection with transparent drinking containers from filled resins which have been characterized as “nano-composites”. Nano-composites are reinforced resins which comprise the resins enumerated above and nanometer-sized filler particles. It has been found that resins containing small amounts of approximately 2-6% of the nanometer-sized particles can provide improvements in mechanical and thermal properties, improvements in gas barrier and flame resistance and do not reduce the light transmission of the resins inasmuch as the nanometer-sized particles are in the same size range as visible light wave lengths. A discussion of nano-composites is provided in Plastics Technology, June, 1999. Accordingly, nano-composites can advantageously be used to injection blow-mold drinking containers such as tumblers and the like. Thus, not only would the transparent nature of the resins be maintained, but the strength of the resin could be improved. For polystyrene, the use of a nanometer-sized filler could improve the strength of the resin and provide more uses of this resin than for just disposable tumblers. Nylon composites are likewise of interest. At present, nanometer-sized clay has been used to form nano-composites. For example, montmorillonite, which is a layered alumino-silicate having individual platelets that measure on the order of 1 micron diameter and have an aspect ratio of 1,000:1 have been added to nylon. Suppliers of the nanometer

montmorillonite are Nanocor, Inc. and Southern Clay Products. For some of the above listed resins, it may be useful to chemically modify the surface of the montmorillonite inasmuch as this hydrophilic clay may not be compatible with the more hydrophobic resins. Surface treatments can include exchanging the inorganic cations on the surface of the clay with materials which can induce hydrogen bonding with the resin including hydrogen cations, ammonium cations, silane cations and the like. Other fillers can be formed chemically or ground to the appropriate size and used as fillers for the injection blow-moldable resins of this invention. For example, inorganic or organic pigments such as zinc oxide, or titanium oxide can be used. Even plastic fillers can be provided in nanometer sizes and added to the blow-moldable resins. The nanocomposites can be formed by forming the resin itself in the presence of the nano-filler particles or by simply melt-compounding the formed resin with the nano-filler particles. During the melt-compounding method of forming nano-clay composites, it has been found necessary to delaminate the clay particles sufficiently so that the ultimate level of reinforcement and transparency can be achieved.

Preforms may be made of a single component such as PET, may be monolayer blends of different materials, or may consist of multi-layers designed to enhance specific properties or to provide a unique feature(s) in the final product. Examples of such unique features are as follows: the addition of a barrier layer for reducing oxygen, carbon dioxide, or water vapor transmission; the addition of a layer with increased thermal conductivity to speed the heating or cooling of the contents of the tumbler.

The addition of adjacent layers each containing a component of a reactive mixture that may be used to promote a property change at the interface of the two layers. An example of such a reactive mixture would be to have incompatible polymers such as PET and polypropylene injection molded into a two-layer preform

with one layer containing sodium bicarbonate and the other layer containing citric acid. The desired effect at the interface would be to facilitate the separation of the two distinct layers that are formed in the tumbler made by the blow-molding process. The purpose of the layer separation is to allow the formation of an air gap between the layers. Such an air gap would provide insulation for the tumbler for keeping hot beverages hotter longer and would also increase the hold time for the customer. Similarly, cold beverages would stay cold longer and the outside of the tumbler would not sweat from moisture condensation. The rim fortification process would fix the two layers at the top of the tumbler and there may be an optional point of attachment at the original gate of the preform at the bottom of the tumbler.

In **Figure 4A**, article **40** is formed from preform **10** and thus has at its upper portion neck **14** of preform **10**, a transition portion **48** as well as a tumbler portion **50**. Portions **48** and **50** correspond to the body portion **22** of preform **10** (radially and axially expanded) whereas a base portion **52** corresponds to bottom portion **22** of preform **10**.

Base portion **52** is generally circular in most embodiments and has a diameter, $\mathbf{D_b}$, that is smaller than the diameter, $\mathbf{D_r}$, of the intermediate article at the portion of the intermediate article where the rim of the tumbler is formed.

An angle **54** is defined between a line **53** joining the outer edge of base **52** and the circumference of the upper portion of the tumbler with a vertical line **55** and is generally referred to as the taper or taper angle of the tumbler. The articles of the invention generally have an outward taper with increasing height as shown, since their upper apertures are larger than their bases. For purposes of brevity, this geometry is simply referred to as an "outward" taper, or simply taper.

Note that the tapered portion of the tumbler also has reverse (or inward) taper regions **58**, **60**, which would not be practical with forming techniques such as thermoforming or injection-molding.

Intermediate article **40** of **Figure 4A** has formed in transition portion **48** a circumferential drive groove **62** suitable for receiving a drive belt **64** which may be used for rotating the article during severing of portion **48** from portion **50**. To facilitate separation there is provided a circumferential notch **66** which is operable as a knife guide for guiding a knife **68** used for severing portion **50** from portion **48**.

That is to say, article **40** shown schematically in **Figures 3** and **4A** is rotated by way of belt **64** while knife **68** is inserted in notch **66** in order to sever the tumbler portion **50** from transition portion **48** to produce a second intermediate article **70** as shown in **Figure 5**.

Article **70** has a base portion **52** corresponding to base portion **52** of article **40** as well as the other features of tumbler portion **50** noted in connection with **Figures 3** and **4A**. There are optionally provided a plurality of flutes **72**, **74**, **76** in a sidewall **78** of article **70**. Sidewall **78** extends upwardly from base **52** to define an upper aperture **80** which is generally circular and has diameter $\mathbf{D_r}$. $\mathbf{D_r}$ is larger than $\mathbf{D_b}$ such that article **70** is stackable with like articles. To finish the tumbler, sidewall **78** is fortified around aperture **80** by one of a variety of techniques, including curling a lip portion **82** of article **70** to form a fortified rim as described in connection with **Figures 6** and following. Note that articles **40** and **70** are optionally provided with an interior raised portion **84** which defines a chime **86** if so desired.

There is shown in **Figures 4B** and **4C** alternate configurations of the first intermediate article provided with flanges as part of the tumbler portion to aid in the formation of a fortified rim. In these embodiments, article **40** has a neck portion **14**, a

transition portion **48**, a tumbler portion **50** and optionally a knife guide notch **68**. Sidewall **78** of tumbler portion **50** has at its upper portion a flange configured to be incorporated into the fortified rim of the tumbler. In **Figure 4B** flange **79** projects outwardly and downwardly from the sidewall; downwardly that is, with respect to a horizontal line **81** from the sidewall. After transition portion **48** is severed, the flange may be utilized to form a rim either by curling it to the sidewall or by cooperation with a rim forming member.

In **Figure 4C** a flange **83** projects inwardly and optionally downwardly with respect to sidewall **78**; that is, downwardly with respect to a horizontal line **81** from the sidewall. Here again, after severing portion **48** the flange may be further curled and incorporated into the rim. It is not necessary to utilize a flange in order to provide a fortified rim as will be appreciated from **Figures 6,7,8, 9, 10** and **11**. Indeed, while horizontal flanges may be readily prepared, flanges with inclination with respect to the sidewall will require more complex mold design and operation, perhaps including severing the transition portion from the tumbler portion while the first intermediate article is still in the mold.

Referring to **Figure 6**, lip portion **82** of article **70** is curled by upper and lower tools, **90, 99**. The curling portion of upper tool **90** is indicated at **92**. Die **92** and lower tool **99** may be heated to or maintained at a temperature of between 275°F to about 350°F during a curling operation as the tools are axially advanced towards each other as shown schematically in **Figures 7, 8** and **9**. It is desirable to rotate die **92** with respect to article **70** during the curling operation. If so desired, one may pre-heat the sidewall prior to curling as noted in United States Patent No. 6,237,791 to *Beck et al.* or provide auxiliary radiant heating as indicated in **Figure 10** at **94** or insulate die portion **92** from the rest of tool **90** as indicated at **96** in **Figure 10**; depending upon the temperatures and materials employed.

Lip **82** may be curled at 360° or more as seen at **98** in **Figure 9**.

Another preferred tooling for providing a rim curl is to use a curling screw apparatus as disclosed in United States Patent No. 6,164,949 to *Lamson*. This apparatus includes an oven and four co-rotating helical curling screws; alternatively, a like apparatus with a single curling screw is seen in United States Patent No. 3,337,919 to *Brown*. The disclosures of the above patents are incorporated herein by reference.

A finished stackable tumbler **100** is shown in perspective in **Figure 11**. Tumbler **100** has a curled fortified rim **102**, sidewall **78** and base **52** corresponding to like parts of articles **40** and **70** described above. Upper aperture **80** is circular in shape and larger in diameter than base **52** so that tumbler **100** is stackable with like articles. The tumbler retains the molded-in features such as flutes **72, 74** and **76** as well as raised portion **84** and chime **86**. Likewise, reverse taper regions are provided in sidewall **78**; that regions where the diameter of the tumbler decreases with increasing height such as at **58** and **60**.

Tumbler **100** is readily differentiated from jars or other containers in that it has a positive taper angle **54** as noted above and is free from threads adjacent its upper aperture **80**. The fortified rim is distinguished from closure flanges and the like since it projects laterally a distance **104** which is relatively small with respect to the aperture diameter, typically from 1½ to 10 times the adjacent wall caliper.

Other modes of fortifying the tumbler rim may be employed. For example, there is shown schematically in **Figures 12** and **13** a rim-forming member **110** with a U-shaped profile **112** folded over sidewall **78** of the tumbler. Member **110** is preferably of the same material as the tumbler and may be heat-bonded therewith to form a fortified rim structure **114** shown in **Figure 13**.

There are numerous other options for fortifying the rim of a second intermediate article of the invention. Another method, for example, is to design the blow-molded first intermediate article so that its transition portion can be further severed so that a portion or band fashioned therefrom can be utilized as a rim-forming member such as member **110.** Alternatively, the transition portion is designed so that it can function as a lid which also provides rigidity to a combined structure after removal from the first intermediate structure and recombination with the second intermediate structure. That is to say, the process of fortifying second intermediate article **70** may include providing a band or lid made from transition portion **48** of first intermediate article **40**. This process may be more expedient than forming a lid or reinforcing member separately and more efficient in terms of material usage. Thus, the process of fortifying the second intermediate article of the invention around its upper aperture comprises fashioning a reinforcing member from the transition portion of the first intermediate article preferably selected from the group consisting of a band or lid and applying the reinforcing member so-produced to the second intermediate article around its upper aperture.

As a still further alternative, there may be provided an end unit such as end unit **116** shown in **Figures 14, 15, 16** and **17** of the double seal type used on polyethylene terephthalate cans as are known in the art. To this end, there is provided a flanged container **118** having a flange **120** about its upper aperture **122,** a sidewall **124** and a bottom **126**. End unit **116** has a curled periphery **128** which is crimped about flange **120** to make a double seal as shown sequentially in **Figures 14, 15. Figure 16** is an enlarged schematic view showing the double seal joint wherein the tumbler is lidded with end unit **116**. A preferred technique for applying the lid is to use a curling tool as disclosed in United States Patent No. 4,559,197 to *Dick et al.*, the disclosure of which is incorporated herein by reference. This results in a double seal

with an upwardly U-shaped portion **130** defined by the lid and a downwardly U-shaped portion **132** defined by flange **120** after it is crimped.

The end unit may include a pull-tab **134** coupled to a localized removable portion indicated at **136**, or, the lid may be weakened around its entire periphery as indicated at **138** in **Figure 17** which is a schematic top view of a lidded tumbler produced in accordance with the present invention. End unit **116** may be metal or plastic, but most preferably is thermoformed from the same material as the rest of the tumbler.

Still yet another method of making the tumblers of the present invention is a coordinated injection-molding, stretch blow-molding process as disclosed in United States Patent Nos. 4,731,011 and 5,753,279 (*Nissei*). The process involves injection-molding preforms on a core and transferring the preforms to a blow-mold in some respects like the process of the '543 patent noted above; however, the preform is expanded both axially and radially to provide for greater orientation. The rim of the preform corresponds to the rim of the tumbler as is shown schematically in **Figure 18**.

In **Figure 18** there is shown a mold **30** having mold halves **32, 34** as well as a stretch rod **36** used to stretch the preform. The preform is expanded to a height **42**; however, the diameter **44** of the tumbler rim corresponds to the diameter of the upper portion of the preform from which it was made. Tumbler **40** is thus formed without the need for severing a portion of an intermediate article. Tumbler **40** is preferably provided with an injection-molded rim **41** which has a thickness greater than the thickness of the adjacent sidewall. The thickness of the rim is indicated schematically at **43**, while the thickness of the sidewall is indicated schematically at **45**. Complex shapes including inward taper region **58, 60** and raised portion **84** of base **52** are readily achieved by way of this process; indeed other stretch molding processes are

likewise possible within the spirit and scope of the present invention. In addition, the rim may be locally thickened or a flange provided so that a lid may be more readily attached to a surface with some radial extent.

Rigidity

Commercially available plastic cups are typically made by injection-molding and/or thermoforming, neither of which techniques induce biaxial orientation. In order to characterize Rigidity, the force required to deflect the cup sidewall at 2/3 of the cup height is measured. This measurement is convenient because it is the location on the cup that the majority of people will grip. To assess Rigidity, an empty (dry) cup is restrained by V-blocks at its base, preferably having a weight placed in the bottom of the cup for stability. A movable probe and a stationary probe are positioned on the surface of the cup in opposed positions across the cup sidewall at 2/3 of the cup's height. The cup is then compressed between the probes and the force required for an inward deflection of specified distance of the sidewall is recorded in lb_f. This value is referred to herein as the "Rigidity" of the cup. Preferably, the Rigidity is measured at 75°F and 50% relative humidity, the features of the test including securing the base of the cup, the height of the cup at which the deflection is measured, the deflection displacement and the force required to cause the deflection. Unless otherwise indicated below, the force required for a ¼ inch deflection at 2/3 cup height is reported as the Rigidity. For comparative purposes and to further characterize the cups of the invention, Rigidity at 1 inch sidewall deflection is sometimes used; in such instances, it is made clear that Rigidity at a 1 inch sidewall inward deflection is referred to. In the event peak force occurs before the specified deflection, peak force is used.

The Rigidity is preferably determined using a JS-1 Rigidity tester modified with a Chantillon Gauge. The Chantillon Gauge is available from:

Chatillon
Force Measurements Division
P.O. Box 35668
Greensboro, NC 27425-5668
919-668-0841 FAX 919-668-2746.

The test method was developed by:

Georgia-Pacific Corporation
Neenah Technical Center
1915 Marathon Avenue
Neenah, Wisconsin 54956
920-729-8415, Test Method TM-4671-OM

As noted above, available cups are usually produced by thermoforming or by injection-molding—neither of which techniques induce biaxial orientation into the product. The Table 2 below shows Rigidity data for two commercially thermoformed 20-oz. PET cups and for a 22-oz. stretch blow-molded cup. Note that the Rigidity is much higher for the stretch blow-molded cup. Normally the stretch blow-molding process that is used for bottle making uses an optimized preform design in order to maximize the physical properties of the bottle produced. The preform used in this case was an off-the-shelf 2-liter bottle preform that was not specifically designed to produce the 22-oz. cup characterized in the table.

Table 2 – Cup Rigidity

Sample	Manufacturing Method	Average Weight (g)	Volume (oz.)	Dry Rigidity (lb_f / 1/4 in. Deflection at 2/3 height)
PET Cup A	Thermoformed	19.886	20 oz.	0.744
PET Cup B	Thermoformed	19.03	20 oz.	0.827
Blow-Molded PET Prototype*	Stretch Blow-Molded	22.53	22 oz.	1.430

* Not optimized for weight distribution or preform design, made by invention method

Relative Cup Rigidity

An equation to describe the Rigidity as a function of its strength to weight ratio is as follows:

$$\text{Relative Cup Rigidity} = (\text{Rigidity}) \times \frac{(\text{Cup Volume})}{(\text{Cup Weight})}$$

where,

Rigidity is the force in pounds required to deflect the sidewall of the cup ¼ inch (usually) at 2/3 height,

Volume is in fluid-oz., and

Cup weight is in grams.

Below in Table 3 are the Relative Cup Rigidities for the cups of Table 2.

Table 3 – Relative Cup Rigidity of 20-Oz. Cups

Sample	Manufacturing Method	Average Weight (g)	Volume (oz.)	$(\text{Rigidity}) \times \frac{(\text{Cup Volume})}{(\text{Cup Weight})}$ (lb_f fluid-oz./gram)
PET Cup A	Thermoformed	19.886	20-oz.	0.782
PET Cup B	Thermoformed	19.03	20-oz.	0.832
Blow-Molded Prototype of Invention	Stretch Blow-Molded	22.53	22-oz.	1.396

Relative Cup Rigidity parameter is a universal way of comparing and organizing data on the Rigidity of PET cups manufactured by different methods such as thermoforming, injection-molding, or IBM to those made by stretch blow-molding without regard to structural features or composition. Broadly speaking for all cups made of PET, whether injection molded, thermoformed, injection blow-molded, or injection stretch blow-molded, our data indicates that: (i) Relative Cup Rigidities of less than **0.6** are characteristic of cups with unoriented sidewall material: (ii) Cups with sidewall material with low orientation have Relative Cup Rigidities between **0.61 and 0.95:** (iii) Somewhat oriented, design fortified or injection molded cups have Relative Cup Rigidities between **0.96 and 1.25**; and (iv) Biaxially oriented PET cups, such as those made by a two-step injection stretch blow-molding process have relative Rigidities of at least **1.26** or often greater than **1.35**.

Less than 0.60	Unoriented
0.61 to 0.95	Low Orientation
0.96 to 1.25	Somewhat Oriented or Fortified
Greater than 1.26	Biaxially Oriented

The Relative Cup Rigidity parameter, while seemingly simple, factors in orientation gains in Rigidity from tensile strength, flexural modulus, and crystallinity that are achieved at low product weights and high surface areas, as measured by the weight of the cup in grams and the liquid volume held by the cup in fluid oz. The parameter provides an easy way to rank the efficiency of a material, process, and/or design to yield stiffness per unit weight and surface area. The volume factors in how the weight of the cup is distributed--accounting for wall thickness and added structural features. The Relative Cup Rigidity parameter is intended to provide a method for comparing lightweight cups of different shapes, sizes, and structural features. The method is dependent on the ability to deflect the sidewall ¼ inch at 2/3 of the cup height.

A series of commercially available and experimental cups were evaluated for Relative Cup Rigidity. Results appear below.

Table 4 – Selected Relative Cup Rigidities

Sample	Material	Method	Cup Volume (oz.)	Cup Weight (grams)	Weight/ Volume Ratio (g/oz.)	Rigidity (lb_f)	Relative Cup Rigidity (lb_f-fluid oz./gram)
C –Red Multi-layer	PS/HIPS	Thermoformed	16	11.82	0.74	0.688	0.931
D – Red Multi-layer	PS/HIPS	Thermoformed	16	13.51	0.84	0.840	0.995
E	PS	IBM*	13.6	18.82	1.38	2.18	1.575
F	PS	IBM*	9.0	13.16	1.46	1.88	1.286
G	PET	IBM*	13.6	24.93	1.83	2.03	1.107
H	White HDPE	Injection Molded	32	36.4	1.14	1.16	1.019
I	White HDPE	Injection Molded	44	49.4	1.12	1.23	1.095
J	PET	Stretch Blow-Molded (one Step)**	14.2	18.62	1.31	1.19	0.908
K		Thermoformed	32	28.01	0.875	0.917	1.048
L	PET	Thermoformed	16	17.58	1.10	0.672	0.612
M	PET	Thermoformed	16	15.5	0.97	0.552	0.570
N	PS/K resin	IBM*	20	17.91	0.86	0.687	0.767
O	White HDPE	Injection-molding	32	36.6	1.14	1.00	0.874

* Experimental tumbler; injection blow-molded without axial expansion
**Experimental Cup; not optimized

Relative Cup Rigidity of the inventive tumblers as compared with other cups is even more striking at 1 inch deflection as is seen, for example, by way of comparison with United States Patent No. 6,554,154, to *Chauhan et al.* The test

procedure of the '154 patent is detailed in Col. 5 thereof and is essentially the test procedure detailed above for measuring Rigidity described above except that the cups are placed on their sides and the force for a 1 inch deflection at 2/3 of the cup height is measured. For purposes of comparison, the above procedure for measuring Rigidity was followed for the cups of the invention (and others enumerated below) except the force required for 1 inch deflection at 2/3 cup height is recorded.

Table 5 below compares the data of Table 1 of the '154 patent for 16 oz. cups with Rigidity data (1 inch deflection) obtained with a nominal 22 oz. (26.4 oz.) cup of the present invention.

Table 5 – Comparison of Relative Cup Rigidity at 1 Inch Deflection

Design	Mean Cup Weight (oz.)	Mean Cup Force at 1 inch deflection (oz.)	Rigidity (lb_f) at 1 inch Deflection	Volume (oz.)	Weight (grams)	Relative Cup Rigidity at 1 inch Deflection
U.S. Patent 6,554,154 "Old"	0.35960	10.210	0.638	16	10.195	1.001
U.S. Patent 6,554,154 "New"	0.33433	9.994	0.625	16	9.478	1.055
Stretch Blow-Molded Cup of Invention (PET)	---	---	5.227 (at 1 inch)	26.4	24.969	5.527

Thus, it is seen that the cups of the invention are over five hundred % (500%) more rigid than cups of the '154 patent at 1 inch deflection on a Relative Cup Rigidity basis. Similar differences are seen with respect to other commercially available cups. Rigidity data (lb_f) appears in Table 6.

Table 6 – Rigidity Values

Sample	Load at .25 inch dflc (lb_f)	Load at .5 inch dflc (lb_f)	Load at .75 inch dflc (lb_f)	Load at 1.0 inch dflc (lb_f) *
Nominal 22 oz. Stretch Blow-Molded PET tumbler	1.690	3.114	4.036	5.227
16 oz. Thermoformed PET	0.789	1.593	2.260	2.722
16 oz. Thermoformed PET	0.669	1.373	2.038	2.999
32 oz. Injection-Molded (PP)	0.730	1.472	2.284	3.153

*Rigidity Value at 1 inch sidewall deflection

It is seen in Table 6 that a tumbler of the invention typically exhibits Relative Cup Rigidity values at 1 inch deflection at least about 65% greater than the other cups tested.

<u>Rigidity Index</u>

The Relative Cup Rigidity parameter may also be modified so as to index the Rigidity of cups of different polymer compositions to biaxially oriented PET cups by normalizing the data to PET. This is accomplished by multiplying the Relative Cup

Rigidity by the ratio of the densities of the polymer to that of PET. Thus, a polystyrene cup may be indexed against a PET cup by multiplying the Relative Cup Rigidity by 1.05/1.33. Table 7 lists typical blow-moldable polymers and their densities. The Rigidity Index thus calculated allows one to compare various cups whether thermoformed, injection-molded, 1-step stretch blow-molded, and IBM (injection blow-molded as described in the '543 patent noted above) cups regardless of their design or material of construction, *see* Table 9. Furthermore, when cup Rigidity is measurable by sidewall deflection, the normalized parameter also extends to filled or reinforced materials such as calcium carbonate-filled polypropylene and to PP nanocomposites. *See* Table 10.

$$\textbf{Rigidity Index} \equiv (\text{Rigidity}) \times \frac{(\text{Cup Volume})}{(\text{Cup Weight})} \times \frac{(\text{Density of Resin})}{(\text{Density of PET})}$$

(units: lb_f fluid-oz./gram)

where,

Rigidity is the force in pounds required to deflect the sidewall of the cup ¼ inch at 2/3 height,

Cup Volume is in fluid oz.,

Cup Weight is in grams,

Density of Resin is the specific gravity of the base resin disregarding the effects of fillers or additives,

and

Density of PET is the specific gravity of PET, which is taken as 1.33.

Table 7 – Densities of Blow-Moldable Resins

Polymer	Grade	Density	Factor to Index Data to PET
PET	Kosa 2201	1.39	1.0451
PET	**Eastapak 9921**	**1.33**	**1.0000**
PS	Styron 685D	1.04	0.7820
PP	Exxon PP 9574 E6	0.91	0.6842
HDPE	Exxon HYA-301	0.954	0.7173
PC	Dow Calibre 200-3	1.20	0.9022
SAN	Tyril 880B	1.08	0.8120
K-Resin	Chevron-Phillips KR03	1.01	0.7594
HIPS	Atofina 825	1.05	0.7895

The stretch blow-molded cups of this invention highlight the differentiating aspects of these cups compared to the various types of cups on the market today. The 22-oz. reverse taper glass shape was used to demonstrate that reverse taper designs with sidewall embossed logos are possible with crystal clear, rigid, lightweight, indestructible characteristics. Design options make it more possible than ever to link Brand identification with cup shape at competitive prices.

Relative Cup Rigidity and Rigidity Index data on fortified brims, made by the top curl method and the can seamer method, are shown in Table 8. Note that without

the advantage of process optimization of preform design and weight to volume ratios, the Rigidities of stretch blow-molded cups made from typical 2-liter bottle preforms are dramatically higher than cups made by other methods—up to 60% higher than the best thermoformed cups and 90-140% higher than typical cups. An experiment was performed by cutting stretch blow-molded PET bottles in two places—3½ inches from the base and 6½ inches from the base. The Relative Rigidities measured on the bottle samples were 0.87 for the 3½ inch sample and 0.79 for the 6½ inch sample. The Relative Rigidities of these samples are low for biaxially oriented PET materials because they did not have brims. Typically a brim can contribute up to 80% of the Rigidity of a thin-walled cup as compared to a similar cup without a brim.

There appears in Tables 9 and 10 comparisons of Rigidity Indices for cups of the invention and various other products.

Table 8 – Rigidities of PET Cups

Description	**Material**	**Cup Weight** (grams)	**Cup Volume** (oz.)	**Cup Rigidity** (pounds)	**Relative Cup Rigidity**	**Rigidity Index**
22-oz. Reverse Taper Stretch Blow-Molded Brim Curled by Can Seamer	**PET**	**24.969**	**26.4**	**1.360**	**1.438**	**1.438**
22-oz. Reverse Taper Stretch Blow-Molded Brim Curled by Top Curl Tooling Structural Ledge	**PET**	**26.561**	**27.1**	**1.781**	**1.817**	**1.817**
Thermoformed						
12-14 oz.	PET					
16 oz.		14.923	14	1.209	1.13	1.13
20 oz.		16.311	16	0.844	0.83	0.83
24 oz.		18.420	20	1.045	1.13	1.13
		21.575	24	0.950	1.06	1.06

Table 8 – Rigidities of PET Cups (continued)

Description	Material	Cup Weight (grams)	Cup Volume (oz.)	Cup Rigidity (pounds)	Relative Cup Rigidity	Rigidity Index
Thermoformed 12-14 oz. 16 oz. 20 oz. 24 oz. 32 oz.	PET	12.920 15.933 20.357 19.000 28.103	14.2 16 20 24 32	0.620 0.681 0.776 0.646 0.789	0.68 0.68 0.76 0.82 0.90	0.68 0.68 0.76 0.82 0.90
Thermoformed 16 oz.	PET	15.764	18.3	0.516	0.60	0.60
Thermoformed 16 oz.	PET	16.249	18.3	0.662	0.74	0.74
IBM (Injection Blow-Molded) 14 oz. Cut Crystal Design 14 oz. Cut Crystal Design	PET	25.105 24.952	14 14	1.960 2.034	1.093 1.141	1.093 1.141
IBM (Injection Blow-Molded) 16 oz.	PET	24.097	16	0.850	0.564	0.56
One Step Stretch Blow-Molded 14 oz. Cut Crystal	PET	20.638	13.9	0.916	0.62	0.62

Table 9 – Rigidities of Cups Made of Different Materials by Various Processes

Description	Material	Cup Weight (grams)	Cup Volume (oz.)	Cup Rigidity (pounds)	Relative Cup Rigidity	Rigidity Index
22-oz. Reverse Taper Stretch Blow-Molded Brim Curled by Can Seamer	**PET**	**24.969**	**26.4**	**1.360**	**1.438**	**1.438**
22-oz. Reverse Taper Stretch Blow-Molded Brim Curled by Top Curl Tooling Structural Ledge	**PET**	**26.561**	**27.1**	**1.781**	**1.817**	**1.817**
16 oz.	Thermoformed Clear PS	12.983	17.6	0.598	0.811	0.63
16 oz	Thermoformed Clear/Colored PS	14.931	18.3	0.617	0.756	0.59
14 oz. – Swirl Shape 14 oz. – Low Faceted Shape 14 oz. – Cut Crystal Design	IBM Clear PS	17.272 14.807 17.244	13.9 14.1 13.7	1.545 0.853 1.513	1.243 0.812 1.202	0.97 0.64 0.94
Red Multilayer 16 oz.	Thermoformed PS/HIPS	10.324	16.1	0.672	1.048	0.82
Blue Multilayer 16 oz.	Thermoformed PS/HIPS	13.881	18.3	0.764	1.049	0.82
Red Multilayer 16 oz.	Thermoformed PS/HIPS	11.332	18.6	0.544	0.892	0.70

Table 9 – Rigidities of Cups Made of Different Materials by Various Processes (continued)

Description	Material	Cup Weight (grams)	Cup Volume (oz.)	Cup Rigidity (pounds)	Relative Cup Rigidity	Rigidity Index
Multilayer 16 oz.	Thermoformed PS/HIPS	14.143	17.8	0.977	1.230	0.97
16 oz.	Thermoformed Opaque PS	9.282	15.9	0.488	0.836	0.65
16 oz.	Thermoformed Opaque PS	9.843	16.2	0.585	0.963	0.76
16 oz.	Thermoformed Opaque PS	9.903	16.1	0.400	0.650	0.51
16 oz.	Thermoformed White PS	11.191	17.6	0.495	0.778	0.61
32 oz.	Thermoformed HIPS/PS	26.126	32.7	1.273	1.593	1.25
32 oz.	Thermoformed White HIPS/PS	28.830	31.9	1.266	1.401	1.10
32 oz.	Thermoformed White HIPS/PS	29.290	32.6	0.971	1.081	0.85
32 oz.	Injection Molded White PP	36.533	31.8	1.059	0.922	0.62
32 oz.	Injection Molded Georgia-Green PP	35.483	32.6	0.748	0.687	0.47

Table 9 – Rigidities of Cups Made of Different Materials by Various Processes (continued)

Description	**Material**	**Cup Weight** (grams)	**Cup Volume** (oz.)	**Cup Rigidity** (pounds)	**Relative Cup Rigidity**	**Rigidity Index**
22 oz.	Injection Molded Colored PP	32.881	25.2	1.350	1.035	0.70
White HDPE 32 oz.	Injection Molded White HDPE	36.567	32	1.001	0.876	0.62

Table 10 – Rigidities of Mineral-Filled Injection Molded Cups are Compared to Stretch Blow-Molded Cups

Description	Material	Cup Weight (grams)	Cup Volume (oz.)	Cup Rigidity (pounds)	Relative Cup Rigidity	Rigidity Index
22-oz. Reverse Taper Stretch Blow-Molded Brim Curled by Can Seamer	**PET**	**24.969**	**26.4**	**1.360**	**1.438**	**1.438**
22-oz. Reverse Taper Stretch Blow-Molded Brim Curled by Top Curl Tooling Structural Ledge	**PET**	**26.561**	**27.1**	**1.781**	**1.817**	**1.817**
44-oz. Car Cup 100% Solvay 1801 PP 90% PP / 10% $CaCO_3$ 80% PP / 20% $CaCO_3$ 70% PP / 30% $CaCO_3$	Injection Molded PP	47.422 50.497 54.290 59.364	44	1.401 1.621 1.798 2.070	1.300 1.412 1.457 1.534	0.880 0.956 0.986 1.038
44-oz. Car Cup 100% PP 97% PP / 3% Nanoclay 94% PP / 6% Nanoclay	Injection Molded PP	47.310 48.392 49.217	44	1.704 1.810 2.029	1.584 1.646 1.814	1.078 1.114 1.227
44-oz. Car Cup – HDPE	Injection Molded HDPE	48.751	44	0.809	0.730	0.519

From the foregoing data, it is seen the cups of the invention exhibit significantly higher Rigidity Index values than one seen with other disposable cups. The observed values may be summarized as set forth in Table 11.

Table 11- Rigidity Index Summary

Cup Type	Observed Rigidity Index Range, lb_f fluid oz./gram
Stretch Blow-Molded Cups of Invention	1.4 – 1.8
Thermoformed PET Cups	0.6 – 1.1
IBM PET	0.55 – 1.15
Thermoformed PS	0.5 – 1.1
IBM PS	0.6 – 1
Injection-Molded PP/HDPE (unfilled)	0.5 – 0.7
Injection Molded PP/HDPE (filled)	0.5 - 1.2

The differences in observed Rigidity Index Values are perhaps better appreciated by reference to **Figure 1**, wherein the observed ranges for the various cups are presented.

Crystallinity

Samples from the sidewall of Thermoformed Cup A, Thermoformed Cup B, and the Blow-Molded prototype of the invention were taken at the top of the sidewall (1 inch down), the middle of the sidewall and the bottom of the sidewall (1 inch up) and in some cases from the bottom of the cups using the following procedure.

Exemplars were cut from either #1 or #2 cork borers and placed in pre-weighed DSC pans that had known amounts of Dow-Corning 340 silicone heat sink compound (zinc oxide and polydimethylsiloxane). The heat sink compound improves thermal conductivity so that good quality first-heating DSC thermal data can be

obtained. Known amounts of heat sink compound were also placed on top of the PET exemplars prior to the lids being clamped onto the pans.

For DSC experiments, samples were taken through heat/cool/heat regimens at heating and cooling rates of 10°C per minute. The DSC instrument was calibrated with an indium metal standard.

Any suitable commercially available machine may be used such as a Perkin Elmer® Pyris® 6 DSC. The instrument is operated in the heating mode method. Data and results appear in Table 12 below wherein % crystallinity is calculated as follows:

$$\% \text{ Crystallinity} = \frac{\Delta H_{melt} - \Delta H_{cc}}{\Delta H^{\circ}} \text{ X } 100\%$$

where ΔH° = 140.1 J/g for PET

ΔH_{melt} = measured heat of melting

ΔH_{cc} = measured heat of cold crystallization

Reference: *DSC as Problem Solving Tool: Measurement of Percent Crystallinity of Thermoplastics*, W.J. Sichina, International Marketing Manager, Perkin Elmer® Instruments.

Table 12 – Thermal Properties of Poly(ethylene terephthalate) Samples Determined by DSC Heating Mode Method

Sample	Sample	Heat Sink Cmpd Weight		Glass Transition				Cold Crystallization		Melting			Crystal-linity
	Weight (mg)	Bottom (mg)	Top (mg)	T_{onset} (°C)	T_{mid} (°C)	T_{end} (°C)	ΔCp (J/g°C)	T_{peak} (°C)	ΔH_{cc} (J/g)	T_{onset} (°C)	T_{peak} (°C)	ΔH_{melt} (J/g)	(%)
(1) PET Thermoformed Cup B (20- oz.)	3.82	1.76	3.42										
Sidewall Top (One inch down)													
First Heating				44	61	-	0.12	142	-3.96	235	241	43.84	28
Second Heating				-	77	80	0.24	150	-5.43	241	246	32.55	19
Sidewall Middle	4.61	3.88	7.66										
First Heating				65	68	70	0.12	102	-4.49	232	246	40.84	26
Second Heating				-	78	86	0.18	152	-5.21	238	248	38.86	24
Sidewall Bottom (One-inch up)	5.69	1.66	3.45										
First Heating				73	74	-	0.31	118	-22.74	231	246	36.81	10
Second Heating				-	78	-	0.17	147	-5.82	237	249	41.80	26
Bottom of Cup	8.23	1.92	3.31										
First Heating				65	67	69	0.35	127	-26.09	231	246	36.74	8
Second Heating				75	80	85	0.14	159	-6.43	235	247	35.83	21
(2) PET Thermoformed Cup A (20- oz.)	5.74	5.95	3.17										
Sidewall Top (One inch down)													
First Heating				-	67	74	0.45	127	-27.09	233	246	38.56	8
Second Heating				78	80	82	0.17	148	-5.21	238	249	41.58	26
Sidewall Middle	6.79	1.86	2.08										
First Heating				70	72	-	0.23	128	-28.19	235	247	39.18	8
Second Heating				74	78	81	0.11	152	-4.30	237	249	44.67	29
Sidewall Bottom (One-inch up)	5.34	2.46	4.64										
First Heating				69	71	74	0.40	128	-28.53	233	247	38.56	7
Second Heating				68	78	90	0.20	145	-5.76	238	249	41.36	25
Bottom of Cup	9.43	1.46	2.84										
First Heating				-	67	75	0.38	129	-30.95	232	247	40.06	7
Second Heating				73	79	-	0.15	146	-3.66	238	249	42.23	28
(3 Prototype	5.99	3.52	1.10										
Sidewall Top (One inch down)													
First Heating				46	61	-	0.10	92	-2.70	239	247	39.64	26
Second Heating				76	81	85	0.18	147	-4.85	232	246	31.94	19
Sidewall Middle	10.89	2.00	4.59										
First Heating				57	59	66	0.07	97	-4.41	236	248	41.12	26
Second Heating				72	80	89	0.14	156	-5.16	238	251	42.84	27
Sidewall Bottom (One-inch up)	11.17	2.05	4.01										
First Heating				61	63	67	0.05	106	-2.90	238	248	43.83	29
Second Heating				77	82	88	0.16	137	-1.14	234	248	35.34	24

The thicknesses of the thermoformed cups was also measured and samples of the blow-molded prototype tumbler were cold stretched in room temperature Instron® Tests and then evaluated further for crystallinity changes. Results appear in Table 13 for cold-stretched samples vs. unstretched samples.

Table 13– Effect of Cold-Stretch on Crystallinity – Blow-molded Prototype

Sample	Sample	Heat Sink Cmpd Weight		Glass Transition				Cold Crystallization		Melting			Crystal-linity
	Weight (mg)	Bottom (mg)	Top (mg)	T_{onset} (°C)	T_{mid} (°C)	T_{end} (°C)	ΔCp (J/g°C)	T_{peak} (°C)	ΔH_{cc} (J/g)	T_{onset} (°C)	T_{peak} (°C)	ΔH_{melt} (J/g)	(%)
Dog-Bone CD Non-Stretch Area	9.36	2.99	3.31										
First Heating				-	66	69	0.07	98	-3.01	226	247	41.12	27
Second Heating				-	81	-	0.17	155	-6.91	237	250	39.01	23
Dog-Bone CD Stretch Area	8.02	3.09	7.92										
First Heating				-	-	-	-	100	-3.01	241	239	48.31	32
Second Heating				-	81	87	0.18	137	-1.59	233	237	32.78	22
Dog-Bone MD Non-Stretch Area	10.02	2.99	3.31										
First Heating				-	68	-	0.06	107	-5.20	219	247	39.64	25
Second Heating				-	80	84	0.12	142	-2.09	239	250	40.97	28
Dog-Bone MD Stretch Area	9.49	1.53	12.49										
First Heating				-	65	76	0.13	88	-7.45	244	250	59.67	37
Second Heating				78	82	85	0.16	146	-5.41	233	248	32.58	19

$$\% \text{ Crystallinity} = (\Delta H_{melt} - \Delta H_{cc} / \Delta H^{\circ}) \times (100\%)$$

Results of the foregoing tests are further summarized in Tables 14, 15 and 16.

Table 14 – Thicknesses of Cups at Four Positions

Position Measured	PET Thickness (mils)	
	Thermoformed Cup B	Thermoformed Cup A
Sidewall Top (One-inch down)	8.5	15.5
Sidewall Middle	10.3	16.6
Sidewall Bottom (One-inch up)	15.0	12.3
Bottom of Cup	42.5	33.0

Weights of a typical cup are: Thermoformed Cup B 19.00 g and Thermoformed Cup A 19.65g

Table 15 – % Crystallinities of "As Received" PET Samples (First Heating DSC Data)

Position Assayed	Crystallinities (%)		
	Thermoformed Cup B 20-oz. Cup	Thermoformed Cup A 20-oz. Cup	Stretch Blow-Molded Prototype
Sidewall Top (One-inch down)	28	8	26
Sidewall Middle	26	8	26
Sidewall Bottom (One-inch up)	10	7	29
Bottom of Cup	8	7	-

Table 16 – MD and CD Films From Stretch-Blow-Molded Prototype Cups Showing the Effect That Stretching (at Room temperature) Has on % Crystallinities

"Dog-Bone" Sample	Crystallinities (%)	
	Non-Stretched	Stretched
MD of Stretch Blow-Molded Prototype Cup	25	37
CD of Stretch Blow-Molded Prototype Cup	27	32

It will be appreciated from the foregoing that the stretch blow-molded cups of the invention exhibited high levels of relatively uniform crystallinity at all levels of the sidewall whereas the thermoformed cups did not. Moreover, room temperature stretching experiments indicate that further crystallinity gains can be realized by optimizing preform design. Thermoformed cup B had relatively elevated levels of crystallinity in its upper portion while thermoformed cup A was more uniform in terms of thickness and crystallinity; albeit at relatively low levels of crystallinity.

While the invention has been described in connection with its numerous features and improvements, modifications to specific examples given within the spirit and scope of the present invention will be readily apparent to those of skill in the art.